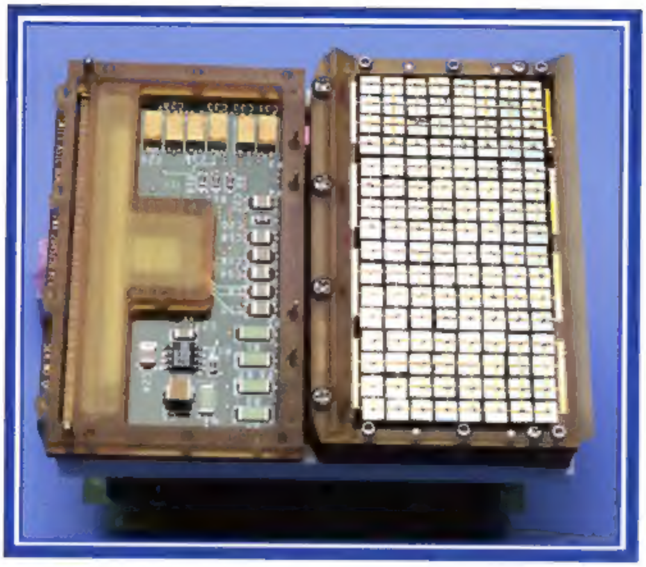
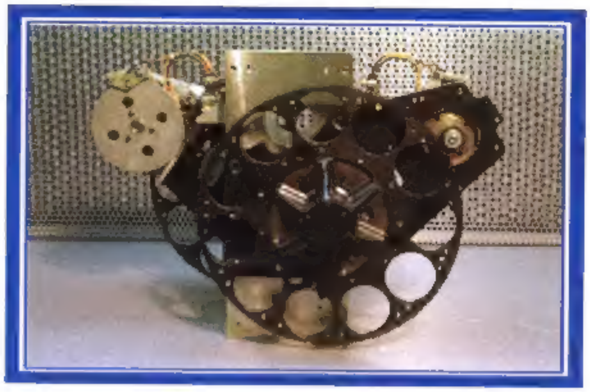

International Gamma-Ray Burst Mission
Swift
Catching Gamma-Ray Bursts on the Fly
NASA
NP-2001-3-210-GSFC

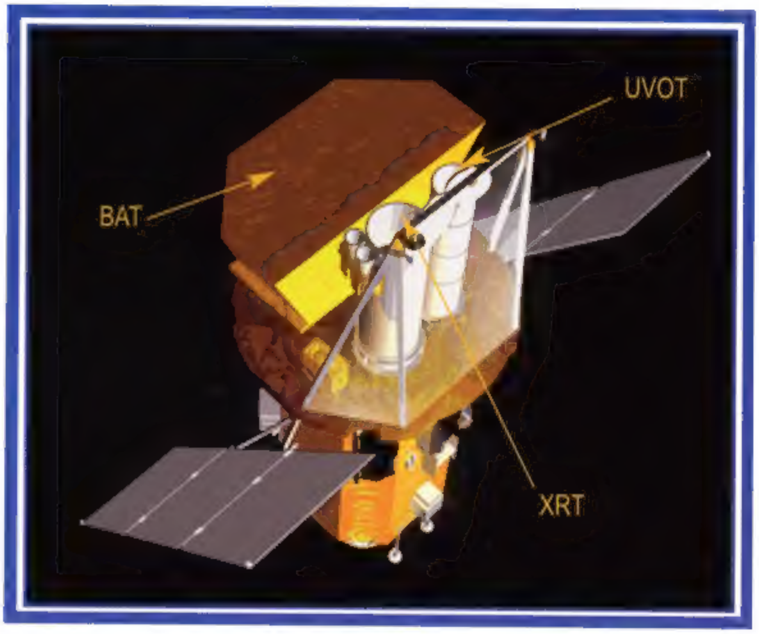


__BAT:__ Detector array and electronics

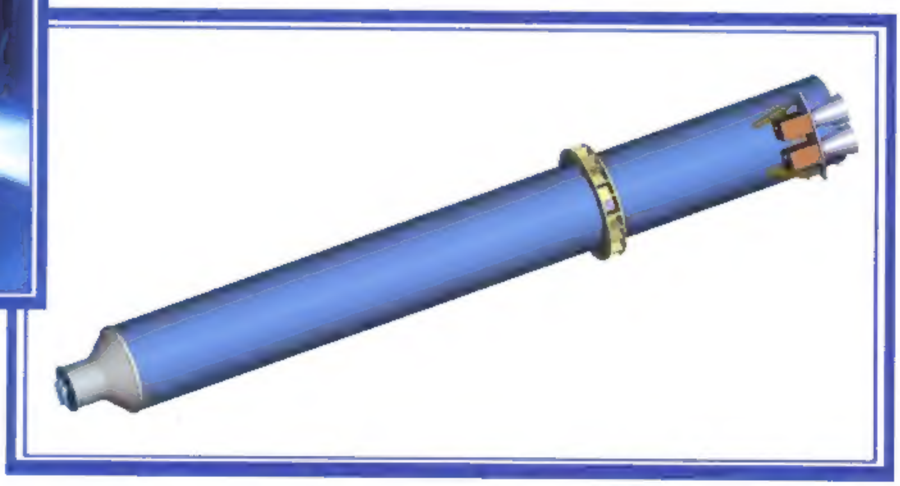


__UVOT:__ UV/optical telescope filter wheel

Swift Instruments



__XRT:__ Mirror



__XRT:__ X-ray Telescope

Catching Gamma-Ray Bursts on the Fly

Gamma ray bursts are the most powerful explosions the Universe has seen since the Big Bang. Satellites detect about one of these bursts a day, and scientists do not know what causes them.

Now there is a satellite dedicated to addressing the gamma-ray burst mystery. Swift, a NASA mission with international participation, is planned for a 2003 launch. Swift will find hundreds of these powerful flashes of light each year.

Swift's three telescopes will scrutinize each burst from beginning to end, looking for clues to its origin. In addition, Swift's trigger system will notify telescopes around the globe – both on the ground and in orbit – about the location of the burst. This way, even the mighty Hubble and Chandra telescopes can turn and get a chance to see the burst's afterglow.

Do gamma-ray bursts signal the birth of a black hole in a massive star explosion, or maybe the collision of two neutrons stars? Perhaps both scenarios are true, or some other exotic phenomenon beyond our comprehension is at work. No one is certain.

Do gamma-ray bursts signal the birth of a black hole in a massive star explosion, or maybe the collision of two neutron stars?

Catching a burst is no easy task. A gamma-ray burst can appear from any direction without warning and may last for only a few milliseconds to just over a minute. Scientists can seldom get a good look before the bursts fade away, never to return in the same location. Swift is built to be agile, to swiftly turn and point its instruments at the burst and relay burst locations within seconds. No satellite turns faster. Swift, in fact, is not an acronym; it is named for the small, nimble bird. Swift, the satellite, will snap up flickering gamma-ray bursts just like the swift bird gobbles up insects. And when Swift isn't feeding on gamma-ray bursts, its telescopes will be searching the sky for other fascinating objects and phenomena.

A Billion Trillion Suns...

In their brief moment of glory, gamma-ray bursts outshine the entire gamma-ray universe. One burst is as powerful as a billion trillion suns. No other single explosion, not even a fantastic supernova, comes close to releasing this much energy. It's easy to see why scientists want to solve the mystery of gamma-ray bursts. The bursts are awesome, plain and simple.

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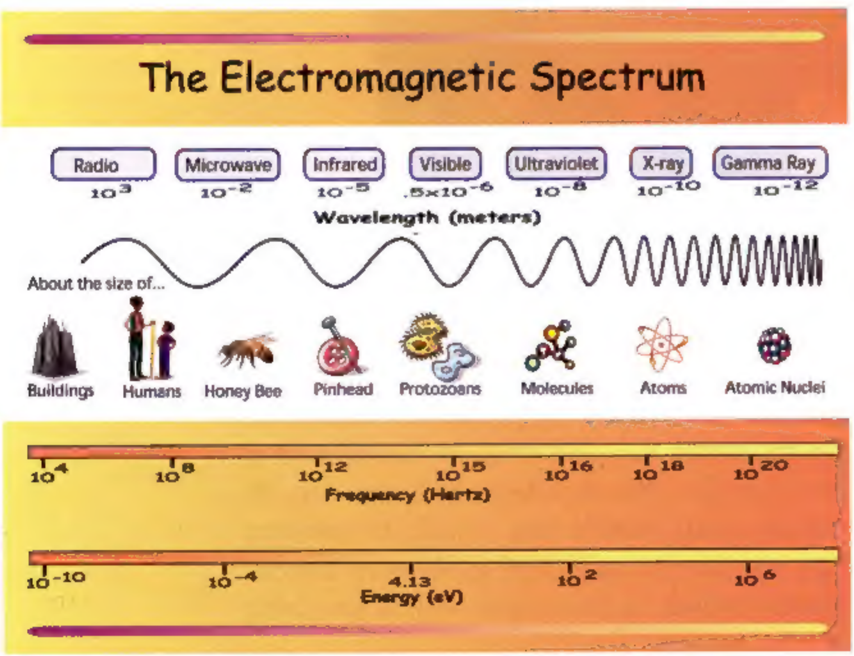
Gamma rays are the most energetic form of electromagnetic radiation, far more energetic than the visible light our eyes can perceive. Electromagnetic radiation, also known as light, comes in many colors and is quantized into discrete packets of energy that we call photons. Radio waves and microwaves are forms of electromagnetic radiation with the lowest energy photons. Infrared radiation is most familiar to us as heat, and has slightly less energy per photon than does visible light. Visible or optical light, the rainbow of colors we can see, is mid-range on the energy chart and is actually but a tiny slice in the entire electromagnetic spectrum. Ultraviolet light is more energetic than optical light; we cannot see it, but we can feel its effects when it causes sunburn. X-rays are so energetic that they can pass right through our skin and soft tissue to create shadows of our bones; that's how doctors make medical X-rays of a broken arm. Gamma rays make up the huge chunk of the electromagnetic spectrum beyond X-rays.

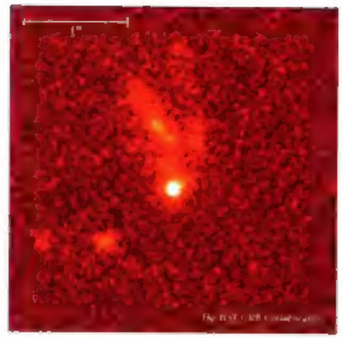
Our Sun shines mostly in infrared, optical and ultraviolet light. The Sun's corona, or atmosphere, which is thousands of times hotter than the solar surface, is hot enough to shine in X-rays. For the most part, the X-ray and gamma-ray sources in the Universe represent the most terrific and violent upheavals, such as the explosions of stars or the flow of fast-moving gas onto a black hole or neutron star.



Gamma-rays are the most energetic form of light.

A gamma-ray has about 1 million times as much energy as a photon of visible light.

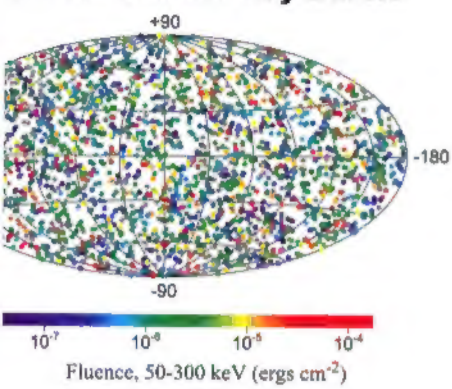
So Energetic, Yet So Mysterious...



Hubble Afterglow

As energetic as gamma rays are, most of them are not able to penetrate the Earth's atmosphere, as do the more familiar radio waves and optical light. The atmospheric gas absorbs gamma-ray photons and blocks them from reaching the Earth's surface. This is one of the reasons why the gamma-ray sky is perhaps the least understood aspect of the Universe. We know so much about optically bright stars – people have been looking up at the night sky ever since we first started walking on this Earth. Gamma-ray astronomy, however, did not begin until the 20th century, when balloons and rockets could get high enough in the atmosphere to measure these gamma rays.

BATSE Gamma-Ray Bursts



2704 BATSE Gamma-Ray Bursts

Gamma rays are also notoriously too hot to handle. Optical light can easily reflect off mirrors and focus onto a detector. Gamma rays would pass right through these mirrors. Scientists must use a variety of instruments to detect gamma rays, depending on the photon's energy. These instruments look more like boxes than telescopes. Photons go in and the instruments measure their energy. But it is hard to pinpoint exactly where the photons come from, unlike visible light hitting a telescope (or our eyes). Gamma-ray instruments traditionally have provided only rough estimates of the location of gamma-ray sources.

The Compton Gamma Ray Observatory (1991-2000) wasn't the first gamma-ray satellite, but it was by far the best to date. Compton recorded, for the first time, a wide range of steady and repeating gamma-ray sources. One of its four instruments, called BATSE, detected over 2,700 gamma-ray bursts. Swift is inheriting BATSE's legacy, but will be able to detect much fainter bursts.

BATSE was the premier gamma-ray burst catcher. There were eight BATSE modules aboard the Compton Gamma-Ray Observatory, and together they could continuously monitor almost the entire sky for gamma-ray bursts. BATSE, in fact, showed that bursts come from all directions and occur about once per day.

Now that scientists know some of the basic properties of gamma-ray bursts, they want to zoom in on the details to try to figure out what causes the bursts. Swift's gamma-ray telescope can only see about one-sixth of the entire sky at any given time, but it will be able to detect fainter bursts within that region... and of course swiftly analyze and relay burst information. Swift observations may hold the key to the long-standing mystery of the origin of gamma-ray bursts.

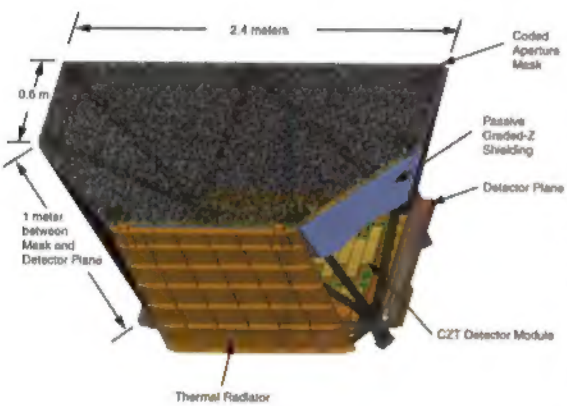
1967 Discovery:

The first gamma ray burst was seen in the year 1967 (although it was not reported to the world until 1973) by satellite-borne detectors intended to look for violations of the Nuclear Test Ban Treaty. What was seen in the data by Ray Klebesadel and colleagues at the Los Alamos National Laboratory was an unexpected, large increase in the number of gamma rays detected on several widely separated satellites. The data indicated that the source of the gamma ray emission was not from the vicinity of Earth, but from a region of outer space! In their discovery paper, Klebesadel et al, reported the detection of 16 such events from July 1969 to July 1972. There was no doubt that the phenomena they reported were real... and that no one had a reasonable explanation for it.

To Catch a Burst...

Swift's gamma-ray burst detector is called the Burst Alert Telescope, or BAT for short. The BAT has two key features for catching gamma-ray bursts. It has a large field-of-view, which means that it can observe large regions of the sky all at once. The BAT is also a coded aperture instrument, which enables it to locate the position in the sky where a burst originates. Coded apertures have many tiny holes to let in light. By determining the shadow pattern cast by the light through the hole onto the detector below, scientists can calculate the location of the burst on the sky.

The BAT will detect and locate, on average, several gamma ray bursts per week. That's 100's of bursts during the mission's expected three-year lifetime. Photons are like gold to a high-energy astronomer. The fact that the BAT can detect so many bursts and has the sensitivity to provide many photons for analysis has many astronomers excited. The BAT may confirm or refute existing theories about differing types of gamma-ray bursts and find new properties as well.



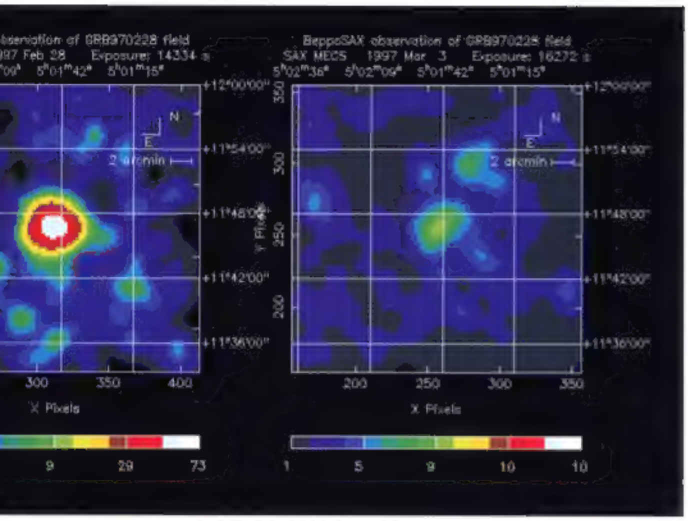
Swift BAT Instrument

When the BAT is not catching bursts, it will be performing a hard X-ray survey of the sky. This is a general observation of the entire sky in the highest-energy ("hard") X-ray waveband (which some call "soft" or low-energy gamma-rays.) The first and only hard X-ray survey was performed in 1979 with the HEAO-1 satellite. Technology has moved forward, and the BAT will be able to reveal a new hard X-ray vision of the Universe with far greater sensitivity. Comparing the BAT all-sky survey to others at different photon energies can tell astronomers a great deal about the shape, history and future of the Universe. Scientists at NASA Goddard Space Flight Center and at the Los Alamos National Laboratory are building the BAT.

Looking at the Afterglow...

Along with the BAT, Swift has two other instruments to study the afterglow of the burst. Much of what we know about gamma-ray bursts comes from our study of the afterglow.

While the burst (the gamma-ray portion of the explosion) only lasts for a few milliseconds to about a minute, the afterglow of the explosion can linger in X-rays, optical and radio light for days – sometimes even weeks for the biggest bursts. The Italian-Dutch X-ray satellite BeppoSAX discovered this afterglow property of gamma-ray bursts in 1997. From the afterglows, scientists have been able to measure the distance to many bursts and also study their host galaxies. We now know that most gamma-ray bursts originate in the farthest reaches of the Universe.



Gamma ray burst afterglow discovered by BeppoSAX

Once the BAT detects a burst in its wide field-of-view, the Swift satellite automatically turns within a minute to aim its X-ray and UV/optical telescopes at the burst. Scientists in Italy, the United Kingdom and at the Pennsylvania State University are building these two instruments. The aptly named X-ray Telescope (XRT) is made up of mostly spare parts from previous Italian and English X-ray telescopes. The XRT provides an even more accurate burst location than does the BAT. The XRT also captures the spectrum, or distribution of X-ray energies, in a given burst.

With a spectrum, astronomers can determine the types of atoms in the burst environment, as well as their temperature and the way the burst fireball interacts with the gas surrounding it. Long, detailed X-ray observations of gamma-ray burst afterglows have been difficult to obtain because the few X-ray telescopes in operation have not been able to point in the right direction until hours or days after the burst. The swift repointing capability of the XRT ensures that most bursts caught by Swift's BAT will be studied in X-ray light.

The same holds true for the third Swift instrument, the UV/Optical Telescope (UVOT). The UVOT will capture the ultraviolet and optical properties of a gamma-ray burst afterglow. The UVOT itself is a 30-centimeter telescope with intensified CCD detectors and is nearly identical to an instrument now being flown on the European Space Agency's XMM-Newton Mission. In space, high above the Earth's clouds and light pollution, the UVOT is as sensitive as a four-meter optical ground-based telescope, until recently the largest in the world. Together, the XRT and UVOT will determine the distances to bursts and collect information about the bursts' host galaxies.

Calling All Telescopes...

Within about 15 seconds after the burst, Swift will relay the burst location to scores of other telescopes, both in orbit and on the ground, so that they can observe the burst or its afterglow.

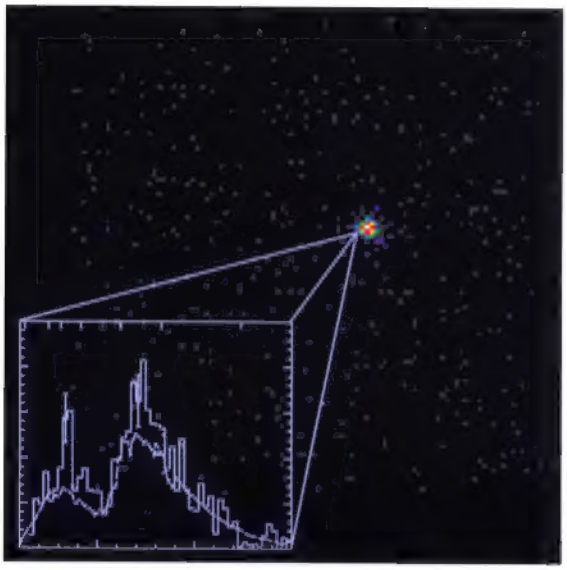
Swift will provide this location to within four arc minutes. That is rather accurate. For example, the full moon is 0.5 degrees in diameter or 30 arc minutes across.

Cosmological Distances

Swift will obtain a large sample of GRBs over a wide range of distances. It will also accurately locate the bursts within individual galaxies. By comparing the distribution of the distances of GRBs to similar existing distributions for galaxies and quasars, Swift will be able to determine how the evolution of GRBs compares to these other two well-studied populations. Comparing the locations of GRBs to regions within a galaxy where stars are forming may gives us clues to the way stars evolve.

The BAT will therefore locate bursts to within about 1/8 of the moon's size. Such accuracy takes much of the guesswork out of where to point a telescope. Earlier gamma-ray burst detectors such as BATSE provided a location to within a few degrees, which left astronomers hunting for the fading burst across vast regions of the sky.

Swift broadcasts the burst position over the Internet by way of the Gamma-ray burst Coordinates Network (GCN). A burst occurs, the BAT detects it, Swift starts turning to the exact source, and a message goes out over the GCN – all within seconds. The message sets off beepers while zipping to astronomers around the world via e-mail. Telescope operators then give the command to turn their telescopes, if available, to the burst location. After about another minute, Swift's XRT is trained on the burst and sends out an even more accurate location for the burst through the GCN.



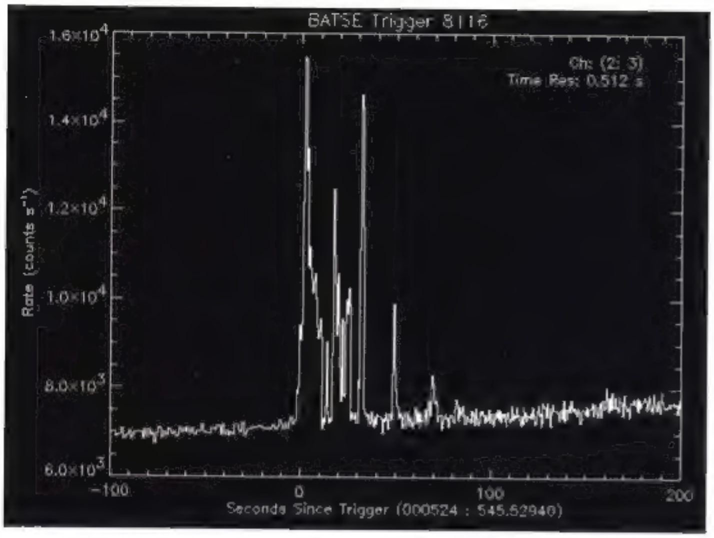
Chandra Energy spectrum of a Gamma-ray burst showing iron line emission.

Often, robotic telescopes on Earth can aim directly at the burst within seconds, for they are "plugged in" to the GCN and do not need any human interaction to start moving. If it is dark and not too cloudy in that region of the world, these optical telescopes just might be able to catch the burst in optical light while it is bursting. So far, this has only happened once, on January 23, 1999. The ROTSE telescope caught a minute-long burst about 20 seconds into the explosion.

A Chandra observation of an X-ray afterglow two days after a December 16, 1999, burst revealed the presence of iron in the explosion. Iron emission lines have now been seen three times in the light spectrum of a gamma-ray burst afterglow. From these spectra, scientists were able to recreate the dynamics of the explosion. The data favor the hypernova, or massive star explosion, model for long bursts. Swift may generate a steady stream of observations similar to this lucky find by Chandra.

Reconstructing an Explosion...

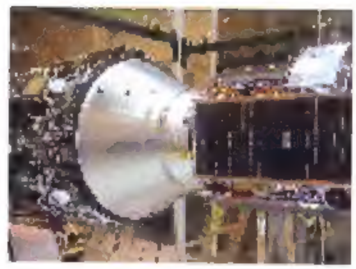
By studying hundreds of bursts captured by BATSE, astronomers have determined that there are two main categories: short bursts that last from a few milliseconds to two seconds, and longer bursts over two seconds. The gamma-ray profile of the two types of bursts look very different from each other: shorter bursts have one set of characteristics while the longer bursts have quite different charactistics. The transition between the two sets of characteristics seems to occur abruptly and almost exactly at the two-second mark. Swift is designed to detect both short and long bursts. Scientists have yet to see a short burst's afterglow, so we are even more limited in our knowledge about short bursts compared to the long variety. The long bursts may be caused by hypernovae, or massive-star explosions.



A longer BATSE gamma-ray burst.

Keeping Swift Company...

Swift is planned for launch in 2003. Depending on the length of each mission, two other NASA satellites may be studying gamma-ray bursts along with Swift.

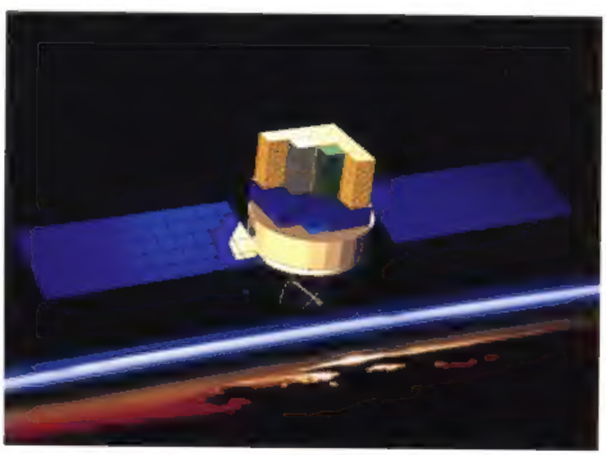


HETE-2

HETE-2, the High-Energy Transient Explorer, is a small international satellite assembled by scientists at the Massachusetts Institute of Technology and launched in October, 2000. This gamma-ray burst hunter is, in many ways, a smaller version of Swift, able to detect and relay information for about 15 or so bursts each year, only without Swift's ability to re-orient for afterglow observations. HETE-2 may very well still be flying when Swift launches.

GLAST, the Gamma-Ray Large Area Space Telescope, is an ambitious observatory planned for launch in 2006. GLAST will have a high-energy Large-Area Telescope (LAT) and a gamma-ray burst monitor which operates at energies similar to Swift's BAT. The LAT will detect the highest of the high-energy photons in a given burst – photons beyond the Swift range. Swift may still be operating when GLAST launches, giving complete burst coverage from visible light to the highest gamma-ray energies detectable from space. This should provide even more clues to solve the gamma-ray burst mysteries.

Gamma-ray Large Area Space Telescope

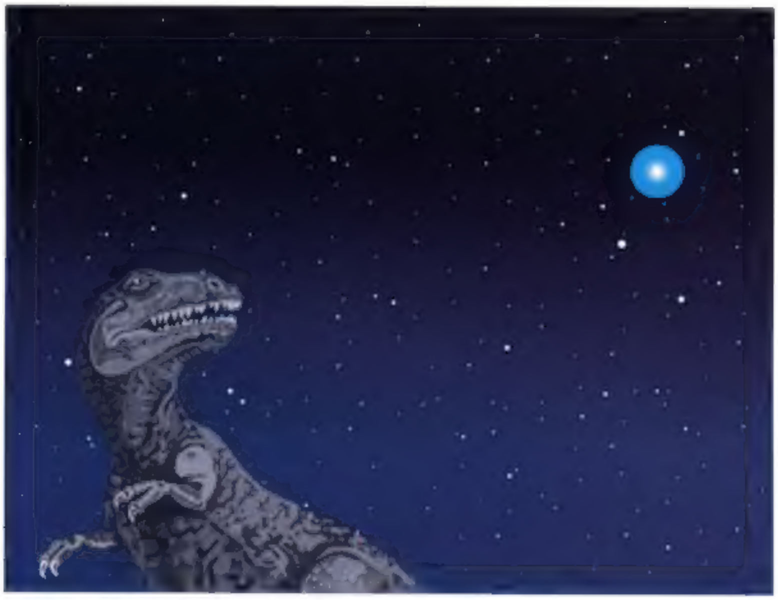


The Answer Within Reach...

... a Gamma-Ray burst could blow away the Earth's atmosphere and cause mass extinction.

If originated nearby in our Galaxy, a gamma-ray burst could blow away the Earth's atmosphere and cause mass extinction. Fortunately, all the bursts observed to date have been from the farthest reaches of the Universe. Some bursts that we have detected may represent the most distant light-emitting objects ever recorded.

Although the bursts themselves are far away, the answers to their mystery may not be. Swift will have the tools needed to address many of the key questions we have about gamma-ray bursts. By solving this mystery, we will enjoy a fuller understanding as well as a greater sense of awe about the Universe and all of its flickering brilliance.



credit: J.C. Rizo-Patron and P.J.T. Leonard

Credits:

Written by:
Lynn Cominsky, Sonoma State University & NASA's Swift Mission, California.
Christopher Wanjek, NASA/GSFC, Maryland.

Special thank-yous go to the following for their useful additions, suggestions and comments:
Neil Gehrels, NASA/GSFC, Maryland .
Laura Whitlock, Sonoma State University, California.
John Nousek, Pennsylvania State University, Pennsylvania.

Cover art and layout by:
Aurore Simonnet, Sonoma State University, California.

GLAST drawing by Timothy Graves, Sonoma State University, California.

Swift Mission Web site -- http://swift.gsfc.nasa.gov/

BAT

Aperture	Coded mask
Detecting Area	5200 cm^2
Detector	CdZnTe
Detector Operation	Photon counting
Field of View	2 sr (partially-coded)
Detection Elements	256 modules of 128 elements
Detector Size	4 x 4 x 2 mm^3
Angular Resolution	17 arcmin
Energy Range	15 - 150 keV
Burst Detection Rate	>100 bursts/year

XRT

Telescope	JET-X Wolter I
Detector	EPIC CCD
Effective Area	110 cm^2 @ 1.5 keV
Detector Operation	Photon counting, Integrating Imaging, & High Timing
Field of View	23.6 x 23.6 arcmin
Detection Element	600 x 600 pixels
Pixel Scale	2.36 arcsec
Angular Resolution	15 arcsec HPD @1.5 keV
Energy Range	0.2 - 10 keV
Sensitivity	2×10^{-14} erg cm^{-2} s^{-1} in 10^4 seconds

UVOT

Telescope	Modified Ritchey-Chretien
Aperture	30 cm diameter
F-number	12.7
Detector	Intensified CCD
Detector Operation	Photon counting
Field of View	17 x 17 arcmin
Detection Element	2048 x 2048 pixels
Astrometry Accuracy	0.3 arcsec @ 350 nm
Wavelength Range	170 nm - 600 nm
Colors	6
Sensitivity	B=24 in white light in 1000 s

Swift Mission

Lifetime	3 years
Mass	1500 kg
Power	1550 Watts
Launch vehicle	Delta 2420
Burst Detection Rate	>100/yr
Position Accuracy	~1 arcsec
Orbital inclination	22°
Repointing Time	75 seconds

Institutions Involved

Area of Support

NASA/GSFC
- BAT, Project Management

Penn State University
- XRT, UVOT, Operations

Leicester University
- X-ray Telescope and Detectors

Brera Observatory (OAB)
- X-ray mirrors for the XRT

Mullard Space Science Lab
- UVOT Assembly

Italian Space Agency
- Ground Station Support

Los Alamos National Laboratory
- BAT Instrument Flight Software

University of California Berkley
- Coordination with other observatories

Spectrum Astro
- Spacecraft Vendor

Sonoma State University
- Education and Public Outreach

http://swift.gsfc.nasa.gov